Acoustic Detection of Ultra-High Energy Neutrinos

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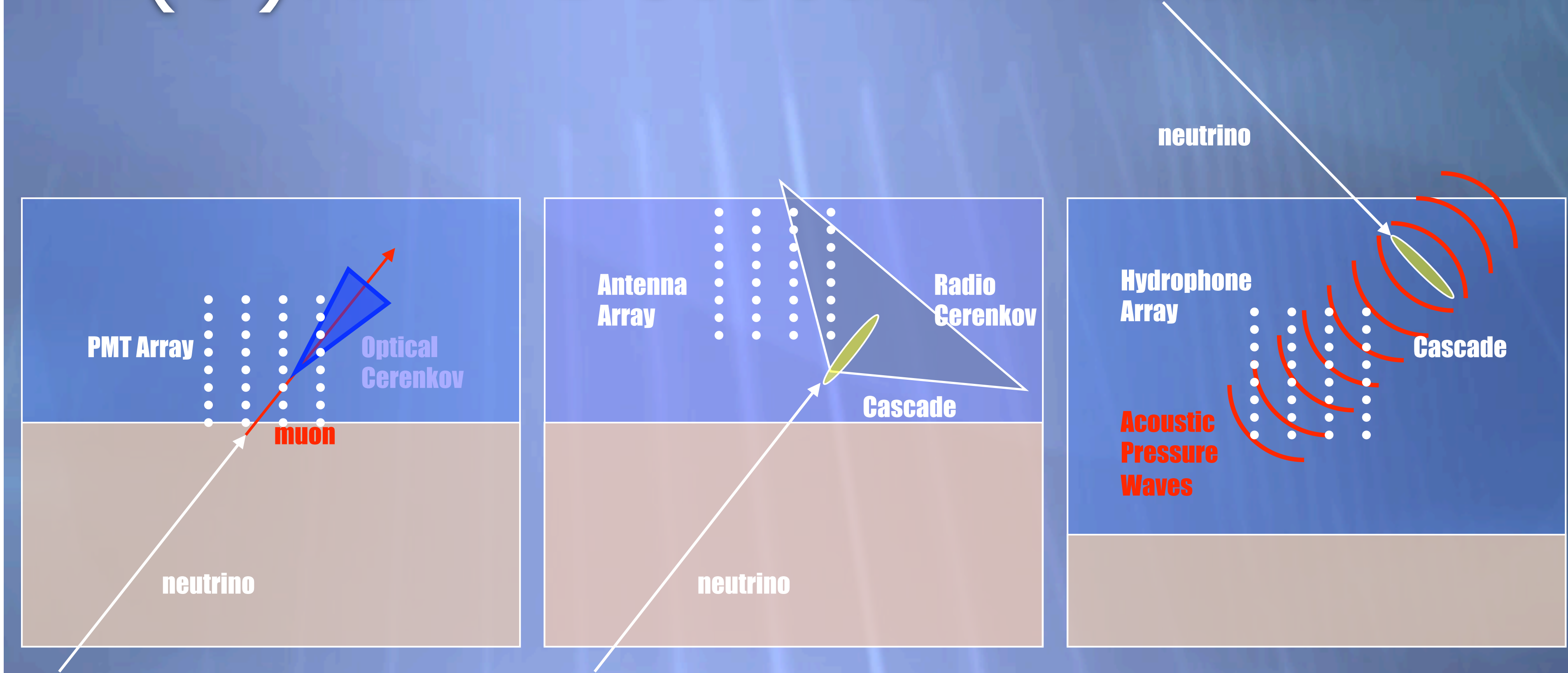
(U)HE ν Detection Methods



Optical Cerenkov

3D array of photosensors

Works well in water, ice

Attenuation lengths of order 50m to 100m (blue light)

Radio Cerenkov

3D array of antennae

Long (order km) attenuation lengths in ice and salt

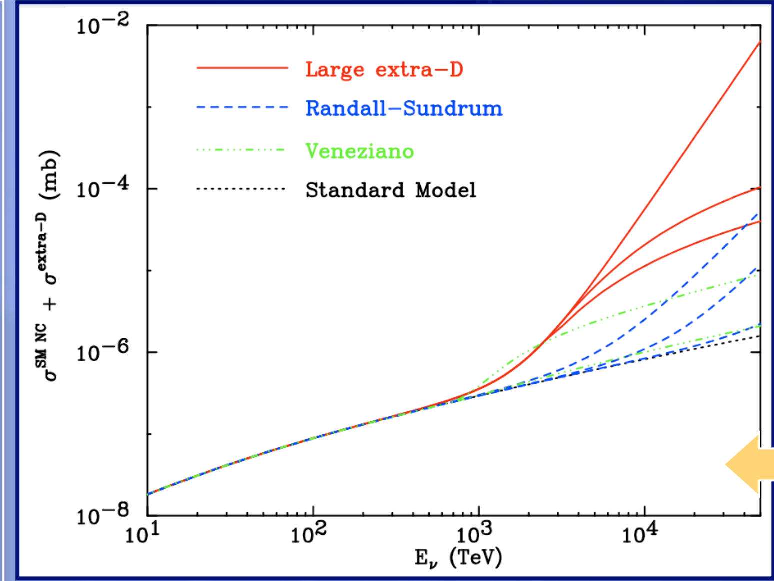
Acoustic Detection

3D array of hydrophones

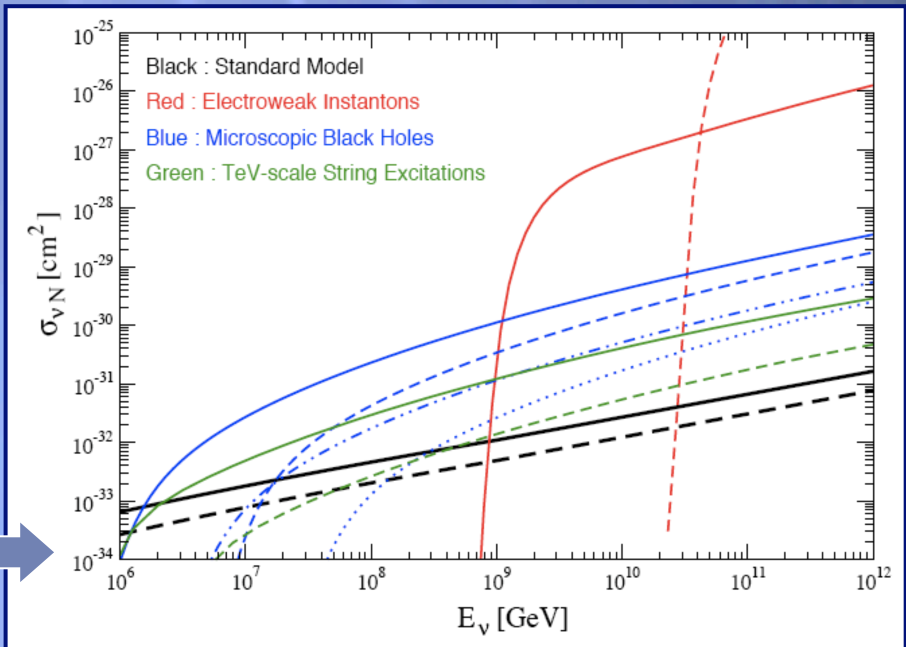
Very long attenuation lengths (order 10km) in water, ice and salt

Motivation

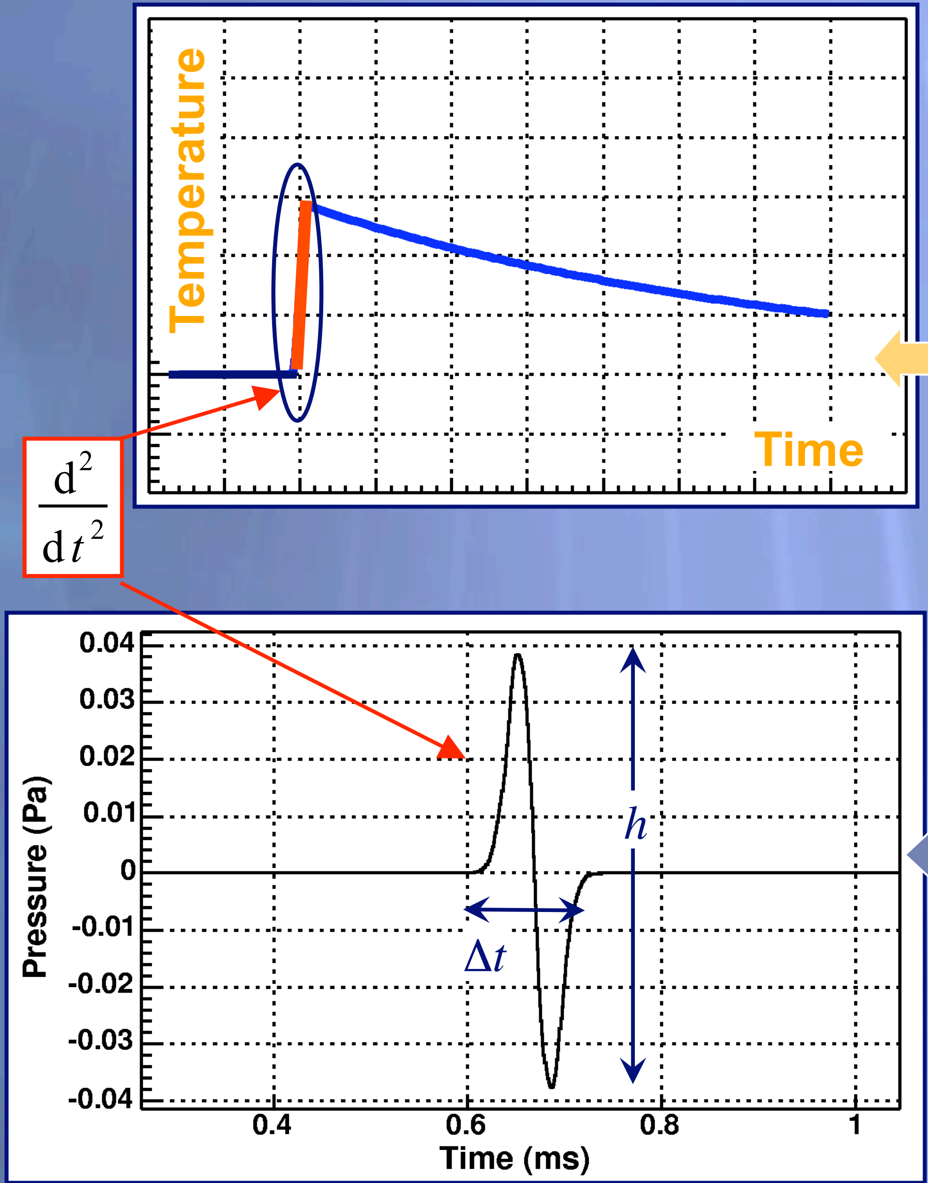
- Probing Ultra High Energies with neutrinos
- *In addition to cosmogenic neutrinos other theories such as:*
  - Strongly interacting neutrinos
  - *New neutral primaries*
  - Violation of Lorenz invariance
  - *Decaying supermassive dark matter*
  - Instantons, excitons
  - *etc…*
- Many of these models predict, e.g. enhanced neutrino cross-sections at ultra high energies



Neutrino-nucleon cross-sections for low- scale models of quantum gravity involving e.g. extra dimensions



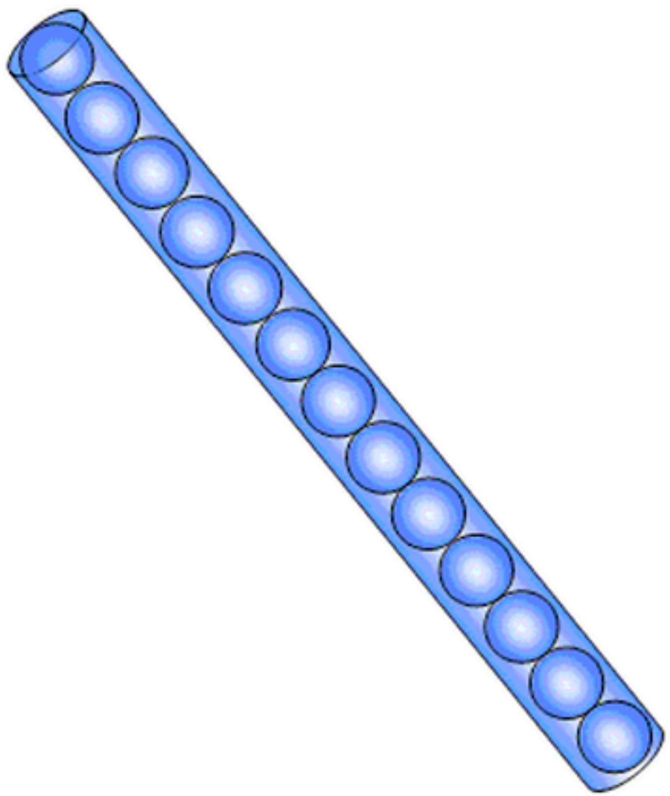
Acoustic Detection Principle



- Fast thermal energy deposition (followed by slow heat diffusion)
- *Results in a quasi-instantaneous temperature increase and expansion of the medium leading to "acoustic shock" sound pulse*

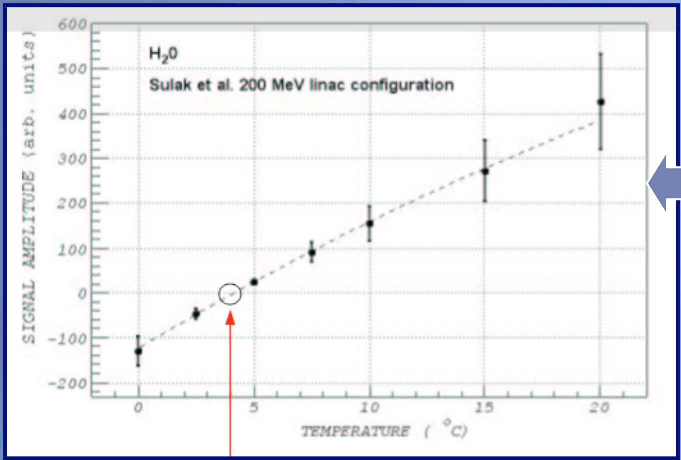
- Double derivative leads to classic bipolar pulse shape
- *Pulse width Δt is related to the **transverse** shower spread*
- Pulse height h is defined by the medium: $h \propto \beta / C_p$ where b is the co-efficient of thermal expansivity and C_p is the specific heat capacity

Acoustic Detection Principle



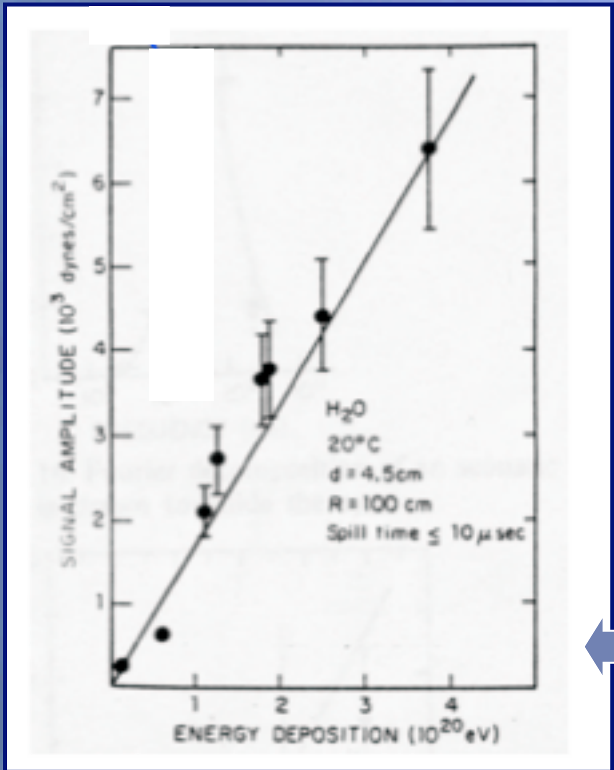
- Cylindrical volume over which the hadronic energy is deposited is typically 10m-20m long and a few centimetres wide
- *In analogy with light diffraction through a slit the acoustic signal propagates in a narrow "pancake" perpendicular to the direction of the shower*

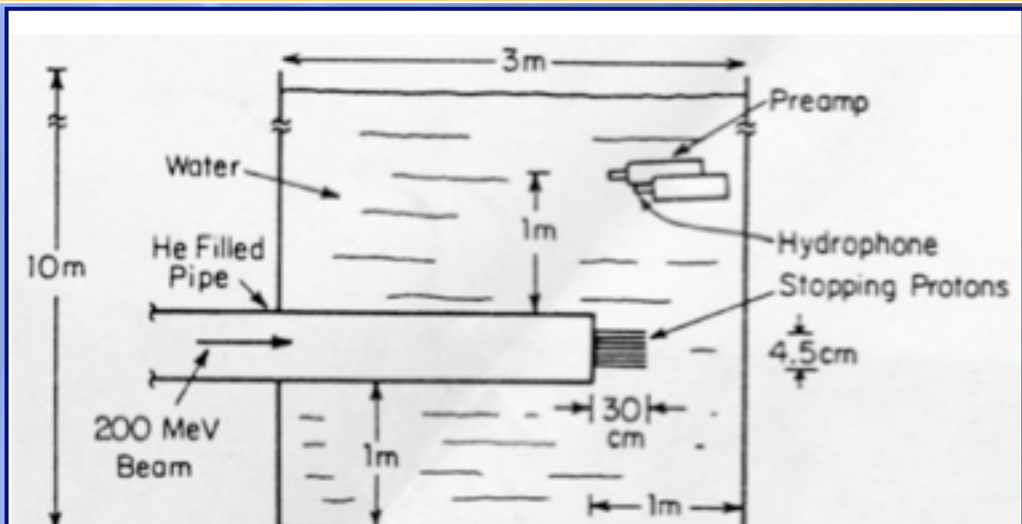
Confirmation of Technique



- Signal amplitude vs. water temperature - warmer is better!
- P proportional to β(T) - thermo-acoustic origin

- Results from experiments in late 1970s confirmed bi-polar acoustic pulse in a test beam at Brookhaven



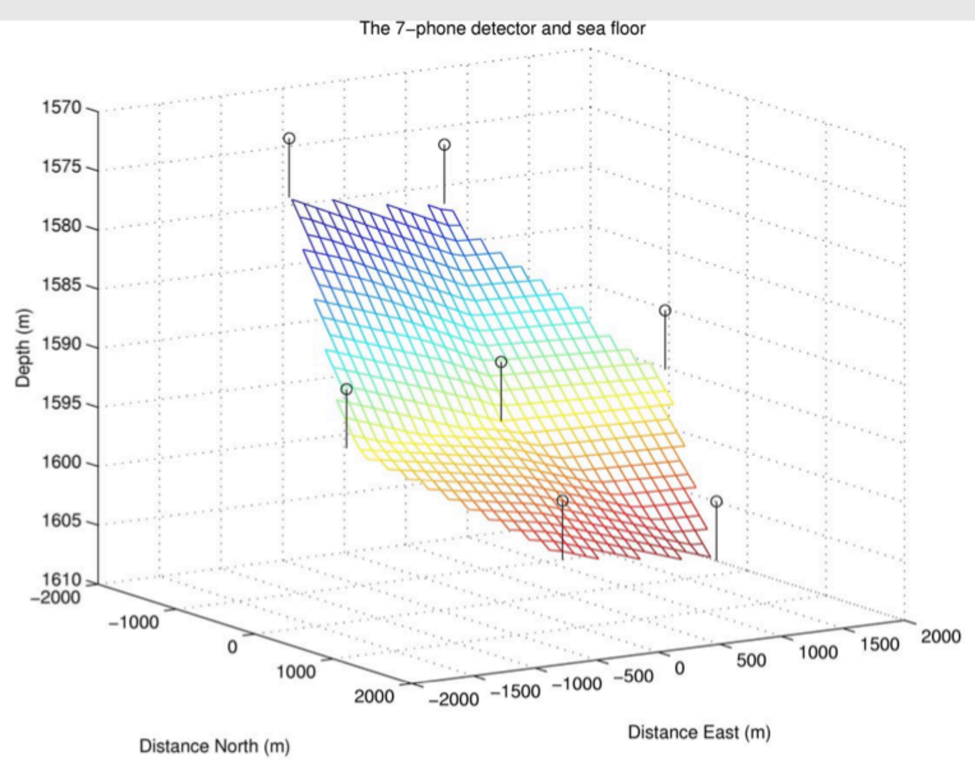


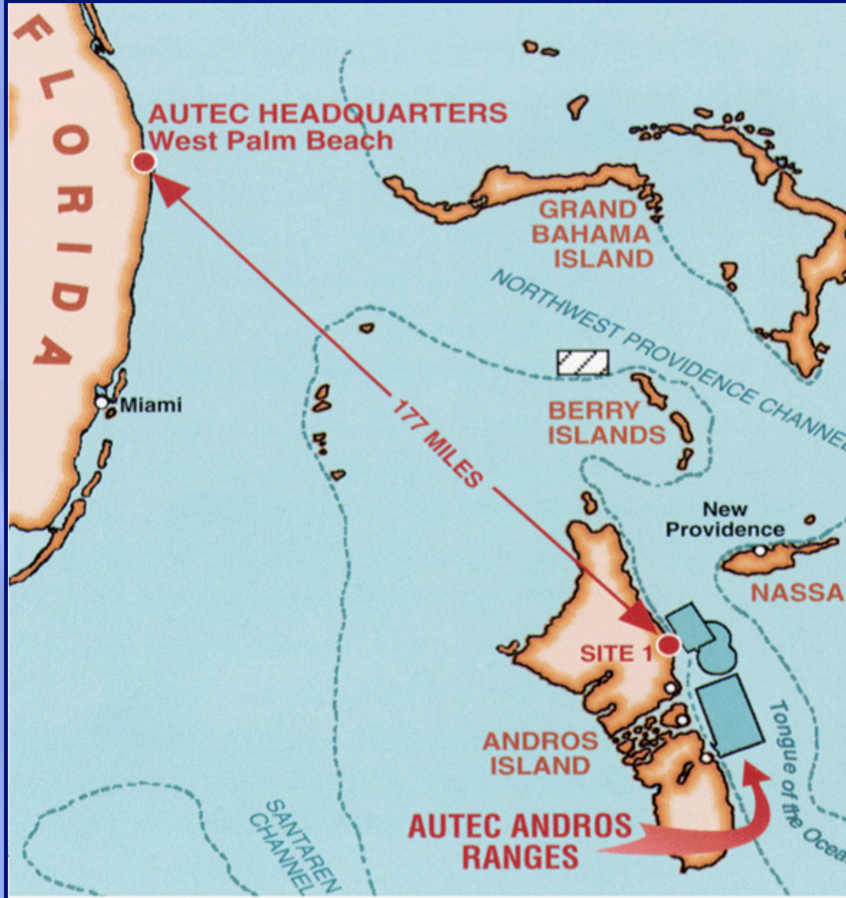
SULAK ET AL NIM 161 (1979) 203

- Signal amplitude vs. energy deposition
- Pressure proportional to Energy - proves predicted coherent effect

Stanford Acoustic Underwater Neutrino Detector (SAUND)

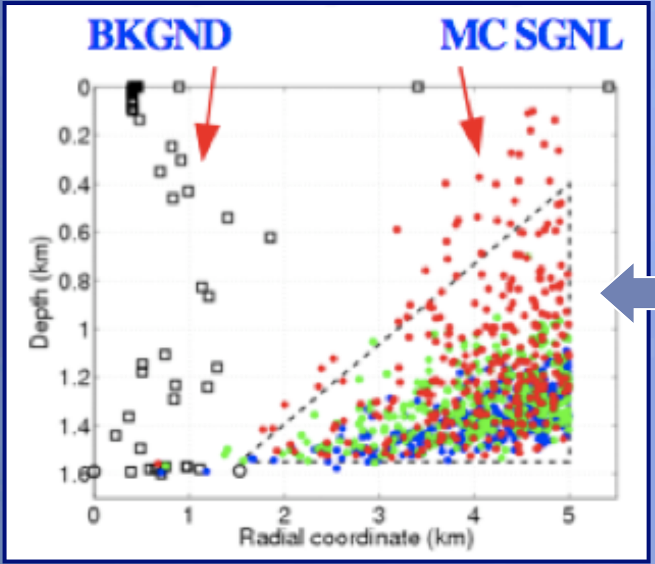
- The SAUND experiment
- *Stanford based venture using the AUTEC array, naval hydrophones in the Bahamas*





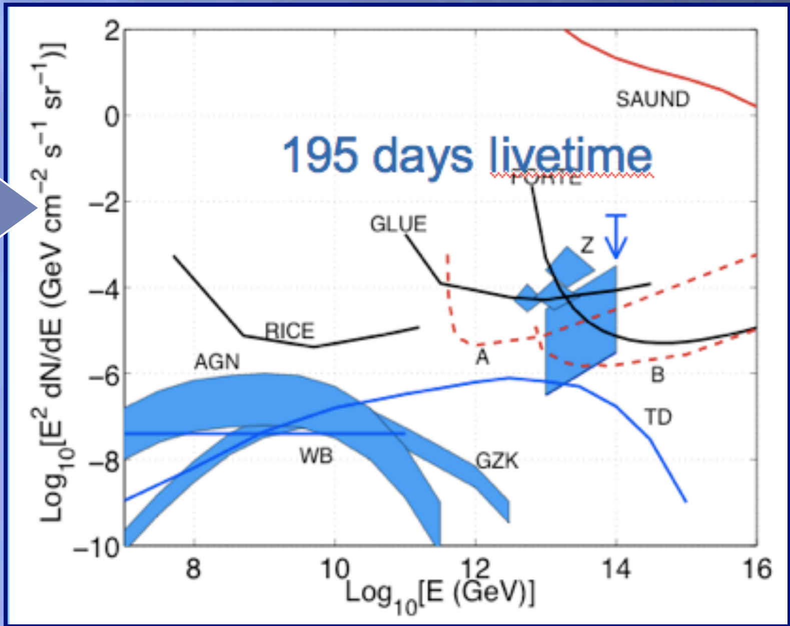
- SAUND I: 7 hydrophones read out
- *Raw data filtered before acquisition*

SAUND

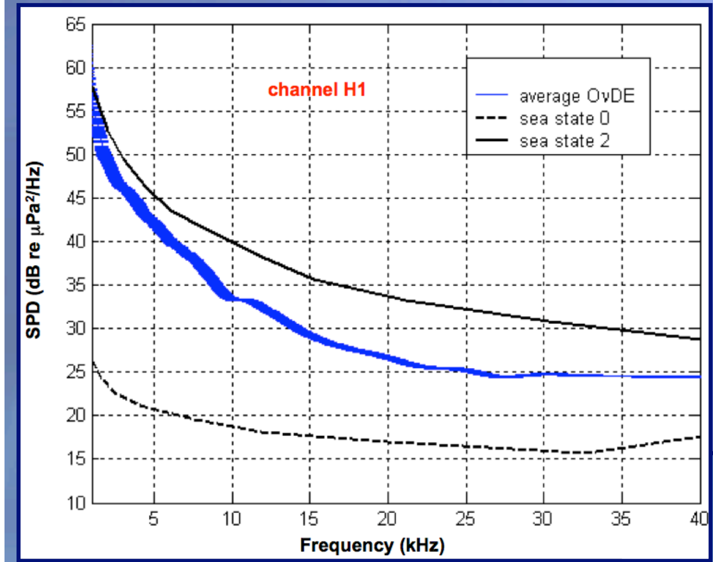


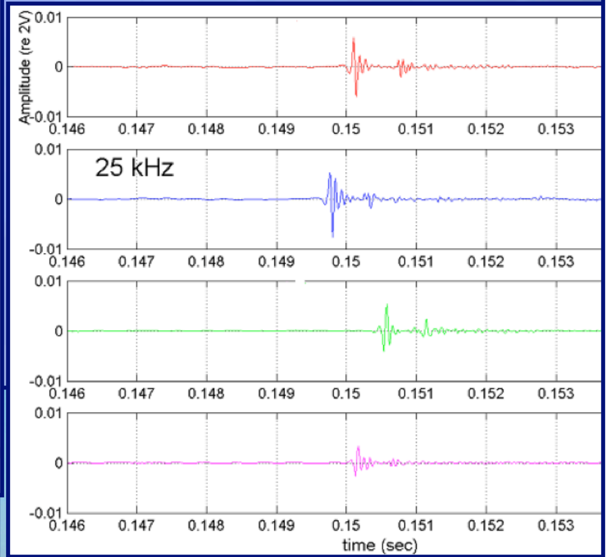
- SAUND analysis requires multi-phone co-incidences and fiducial cuts to remove the remaining multi-polar backgrounds

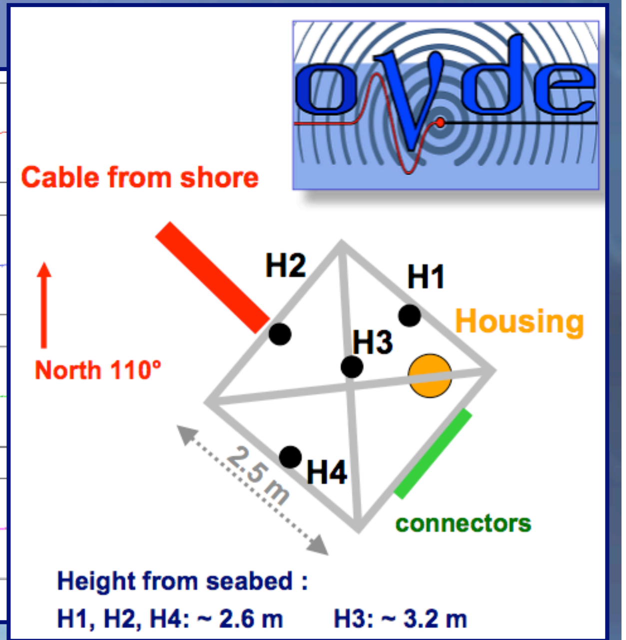
- Published sensitivity for 195 days of data with SAUND I
- SAUND II is reading out ~56 hydrophones and started data taking in summer 2006



Ocean Noise Detection Experiment (ONDE)



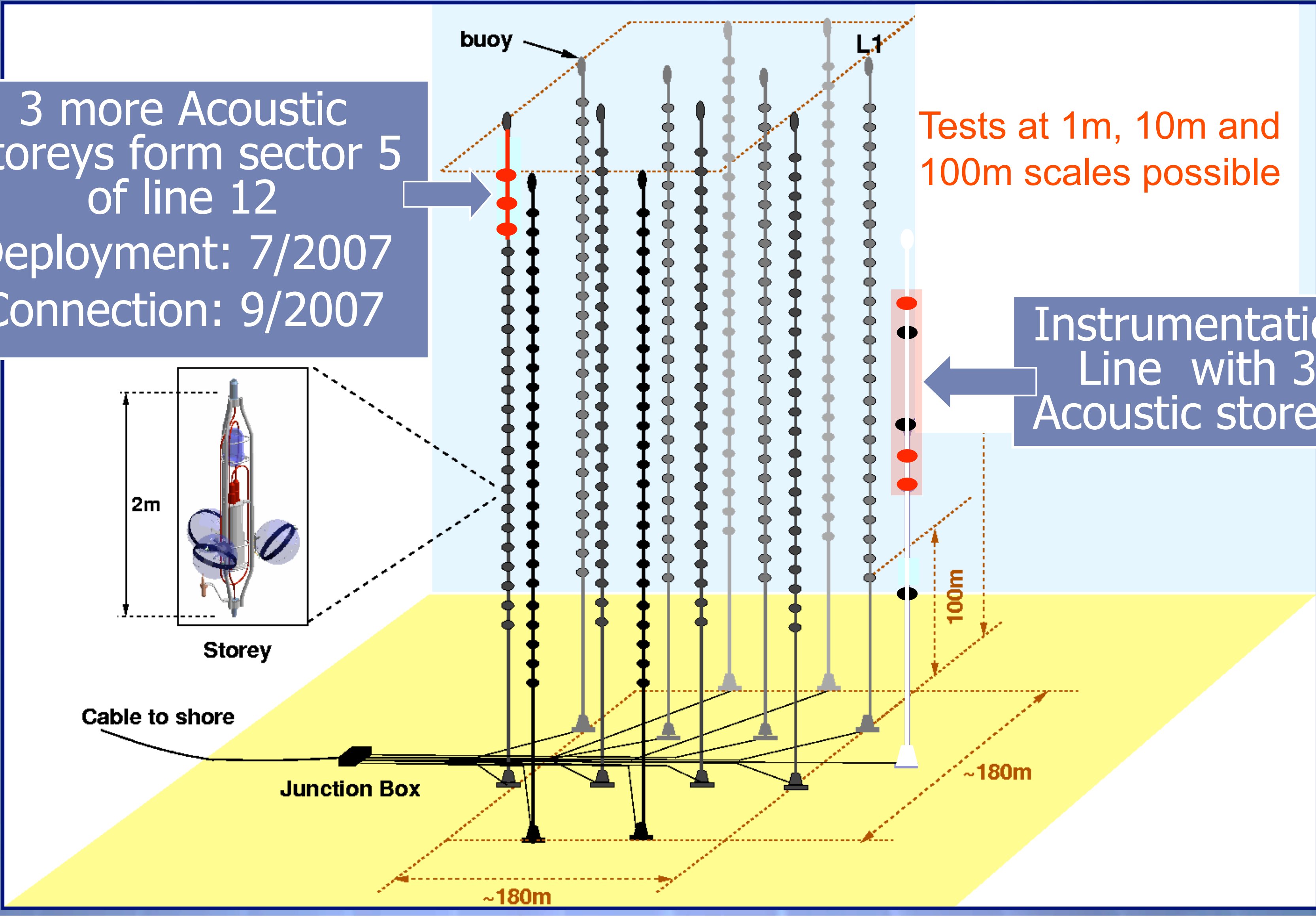




- ONDE was deployed in January 2005 at the NEMO Test Site in Sicily
- *4 hydrophones werer read out (5′ per hour) for ~2 years*
- Full analysis of noise (by hour, month, etc.)
- *Bio coincidences seen*

Antares Modules for Acoustic Detection Under the Sea (AMADEUS)

3 more Acoustic Storeys form sector 5 of line 12
Deployment: 7/2007
Connection: 9/2007

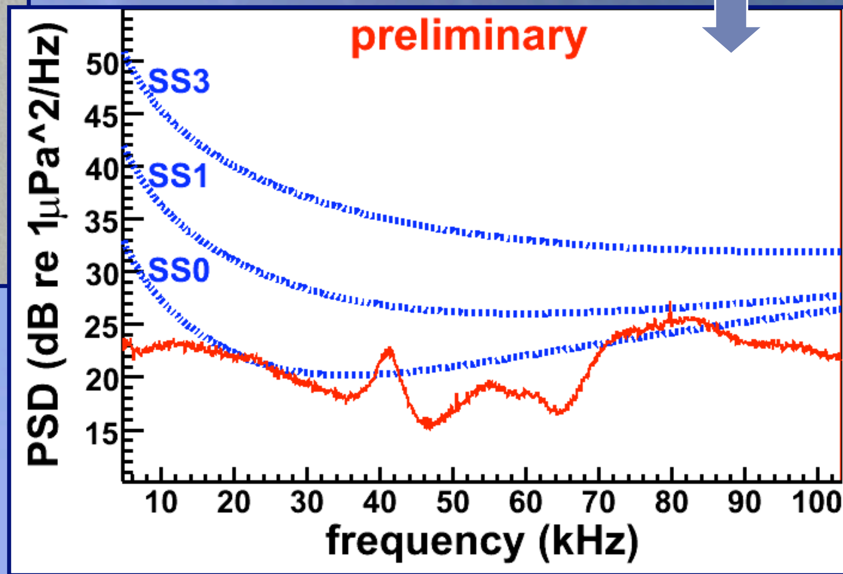


Instrumentation Line with 3 Acoustic storeys

AMADEUS

Hydrophone:
Piezo element with pre-amplifier and filter in PU coating

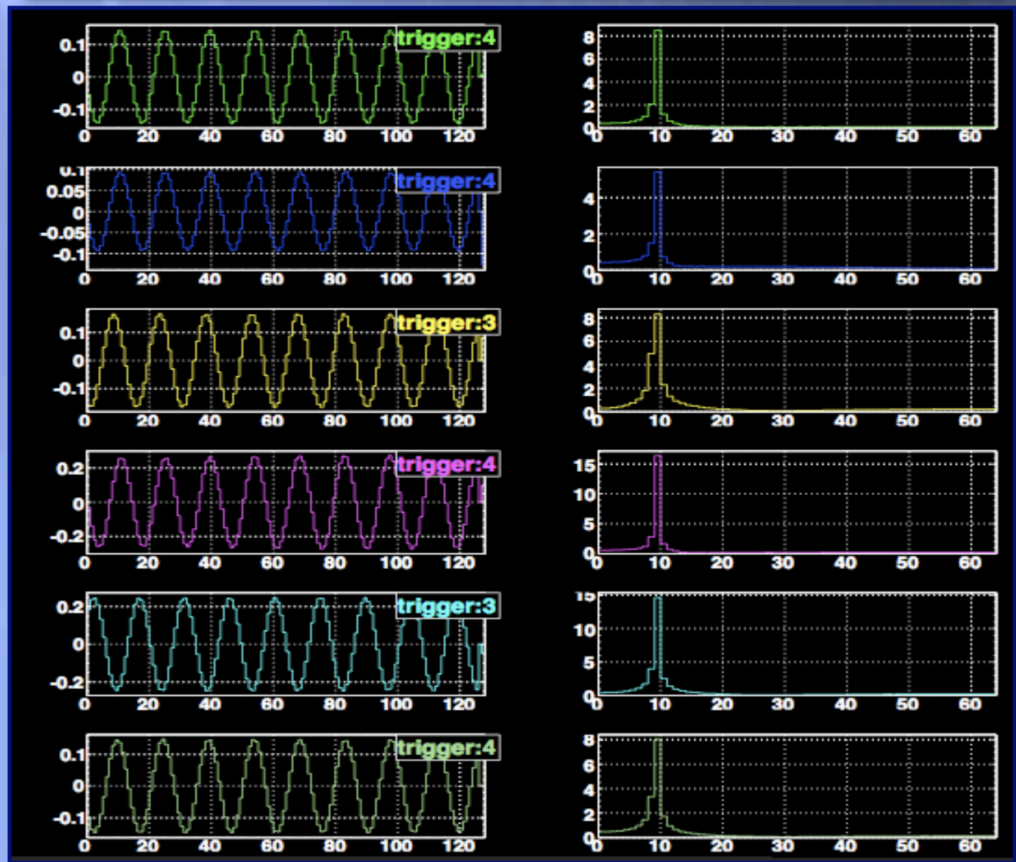
- Acoustic system in connection with ANTARES
- *2 lines instrumented with acoustic sensors*
- Intrinsic sensor noise measured



These studies will be extended to KM3NeT

Acoustic Cosmic Ray Neutrino Experiment (ACORNE)

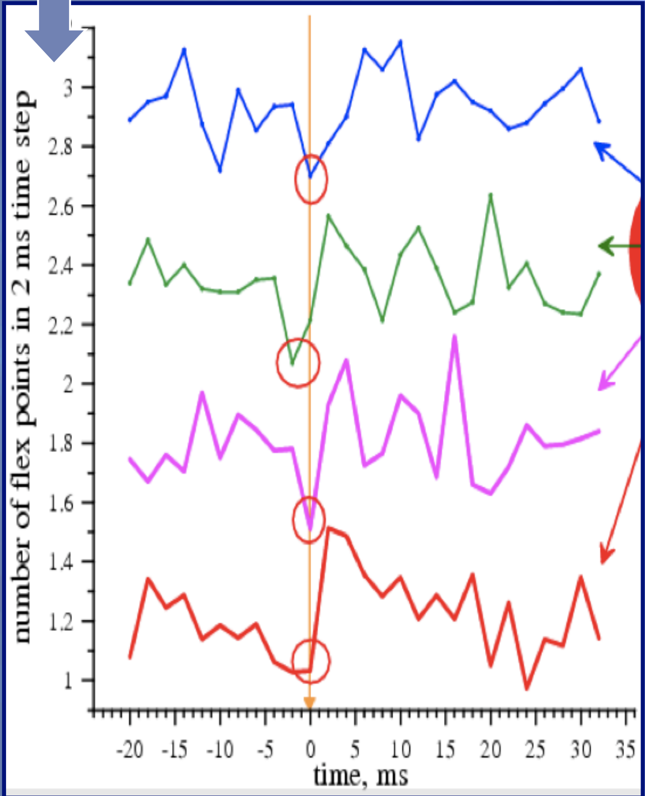
- 8 hydrophones read out continuously at 16bits,140kHz - a total of (~15Tb)
- *Average spectra show hydrophones are well-balanced*

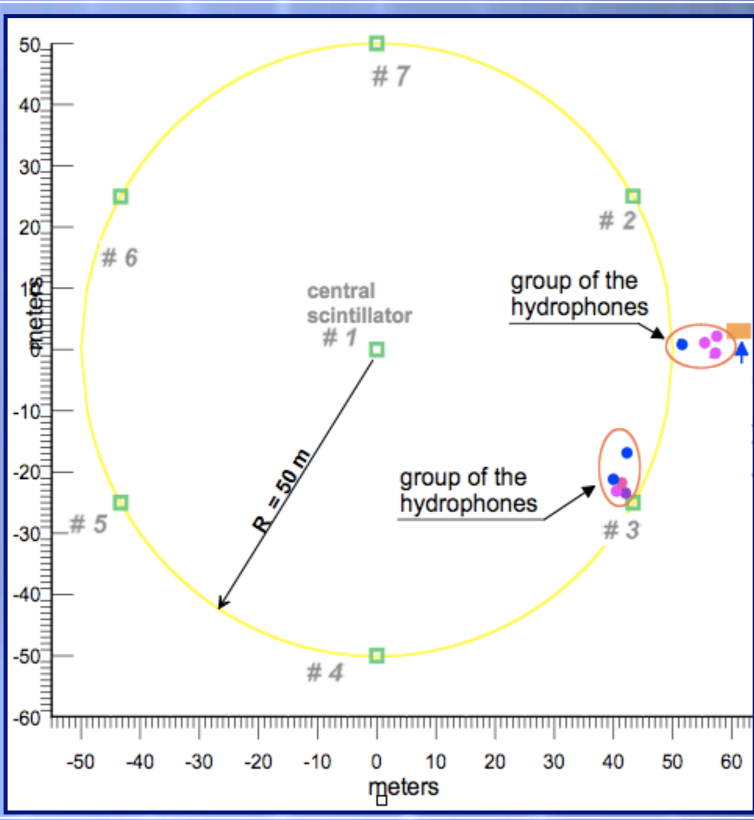


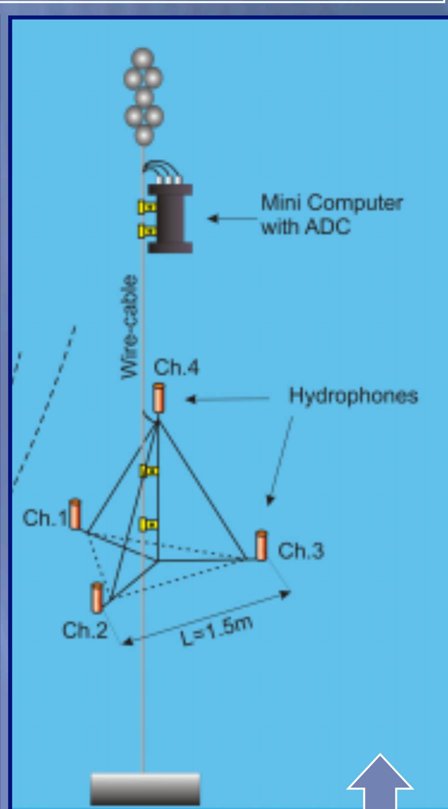
- Rona hydrophone array, a military array in Scotland used by the ACORNE collaboration
- *2 weeks of <u>unfiltered</u> data taking in December 2005, quasi-continuous since September 2006*

Lake Baikal

- Co-incidence of surface (ice) based scintillators and hydrophones
- *Data taken at the Lake Baikal NT-200 site during spring ice cover 2002 and 2003*
- Analysis in progress looking for features in acoustic signals in coinc. with EAS



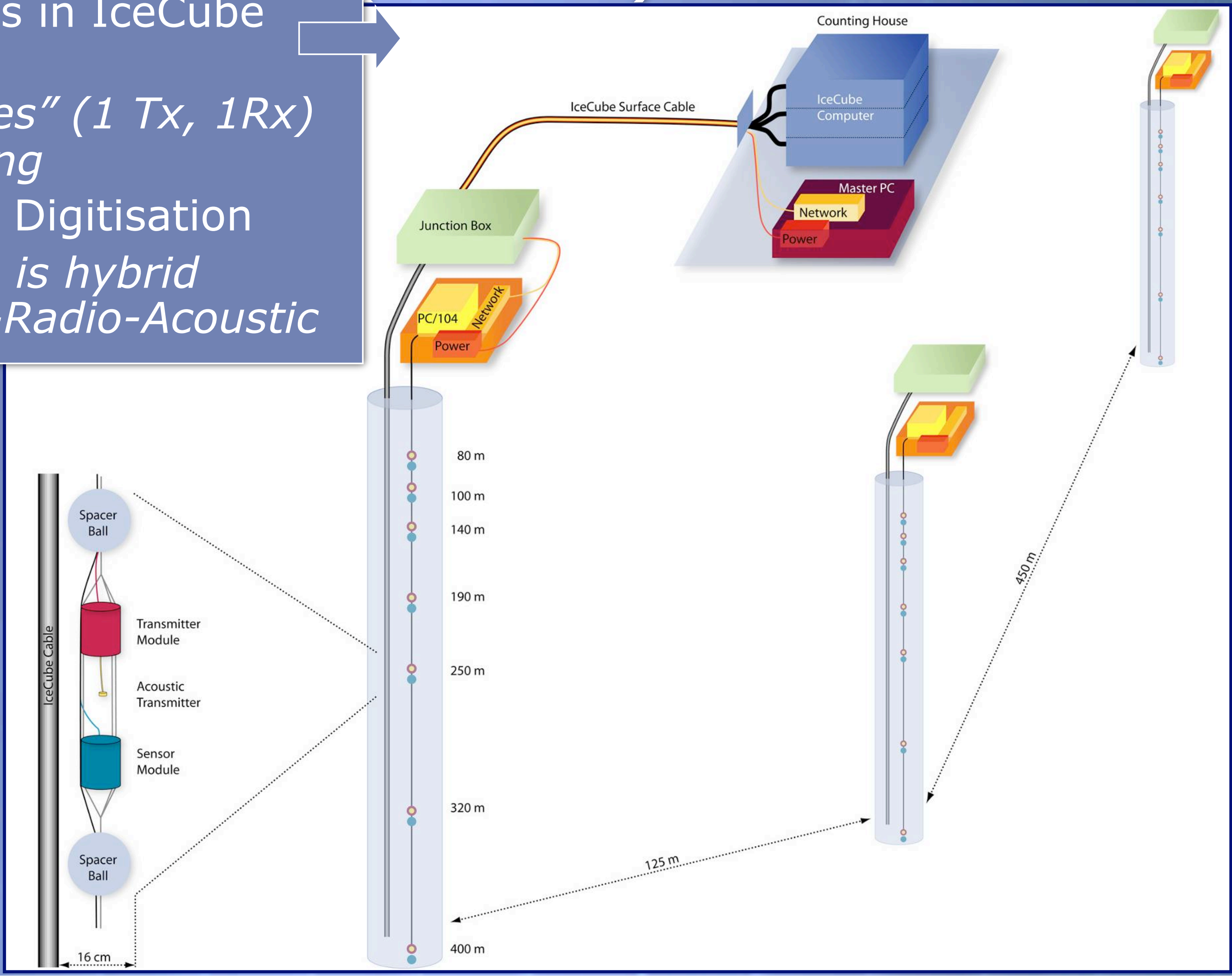




- New acoustic module with 4 hydrophones deployed in April 2006
- *100m, autonomous, self-triggered, on-detector processing*
- First results to be presented at ICRC conference

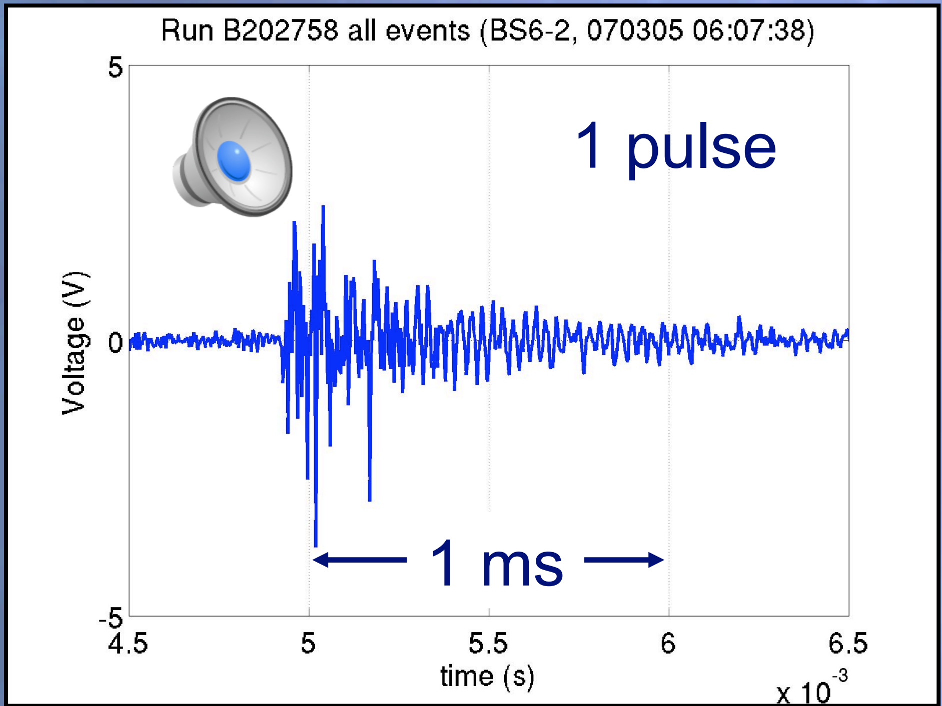
South Pole Acoustic Test Setup (SPATS)

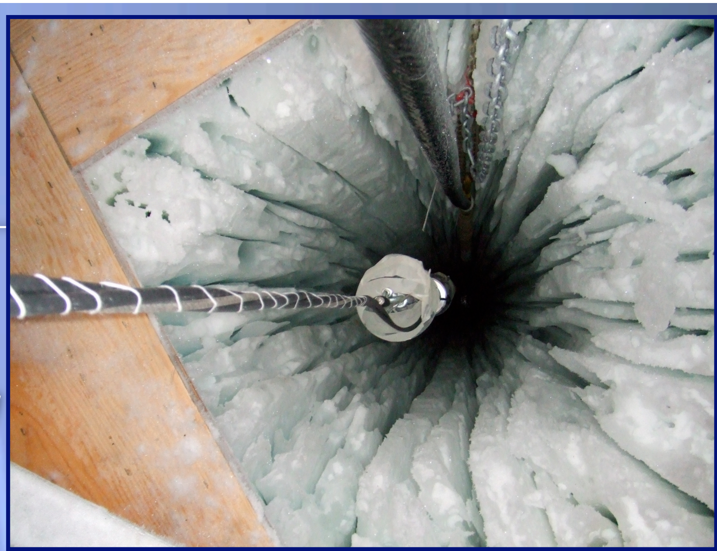
- 3 strings in IceCube holes
- *7 "stages" (1 Tx, 1Rx) per string*
- Surface Digitisation
- *1 string is hybrid Optical-Radio-Acoustic*

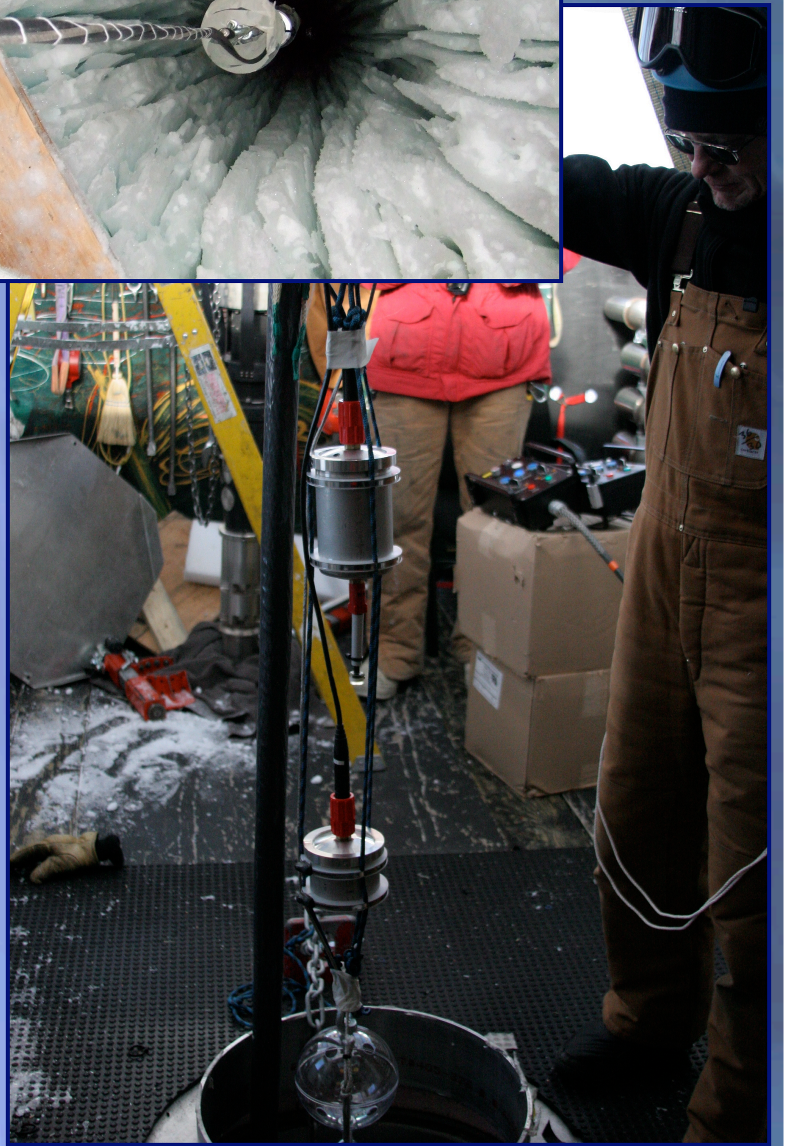


SPATS

- Almost continuous data-taking since Feb '07:
  - *threshold/forced background runs*
  - inter-string Tx-Rx tests
  - *min-max distances: 125m-529m*

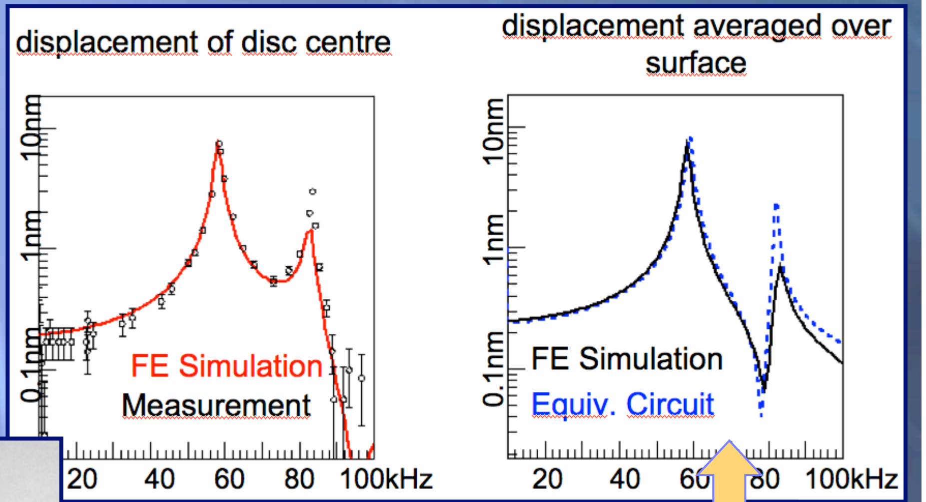


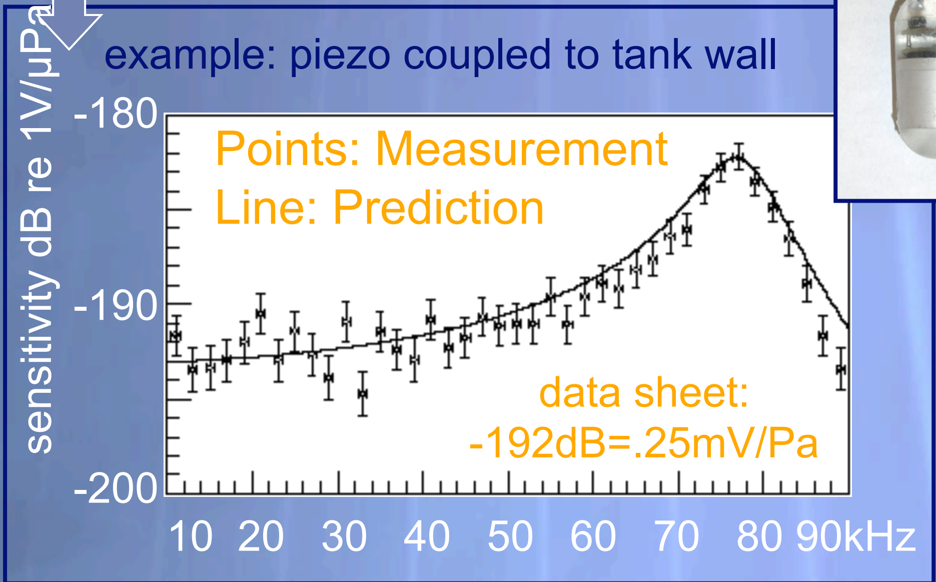




Sensor Development

- Can we design and build bespoke acoustic sensors with performance well-matched to expected signal?
- *Requires a good theoretical model of piezo and the coupling*
- Predictions using equivalent circuits





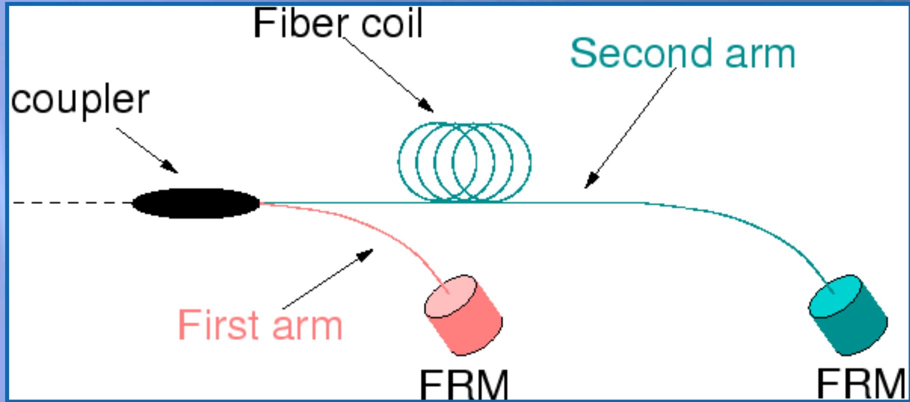
Further detailed understanding of piezos is under study

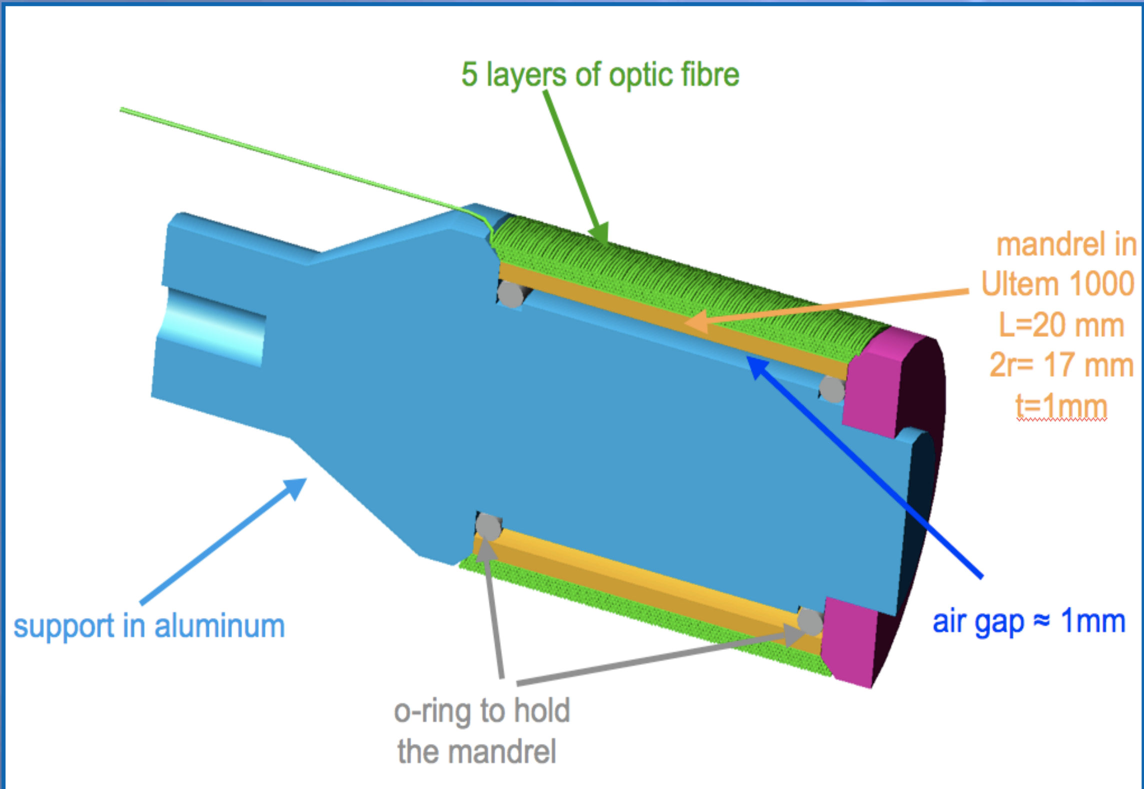
*At the **microscopic** level piezos can be modelled using PDEs for an anisotropic material*

- Solve using Finite Element Analysis
- *Use Laser Interferometry to compare results*

Sensor Development

- Development of novel hydrophone designs
- *From Genova: an air-backed mandrel hydrophone*
- Incorporates a Bragg grating, interferometer and laser

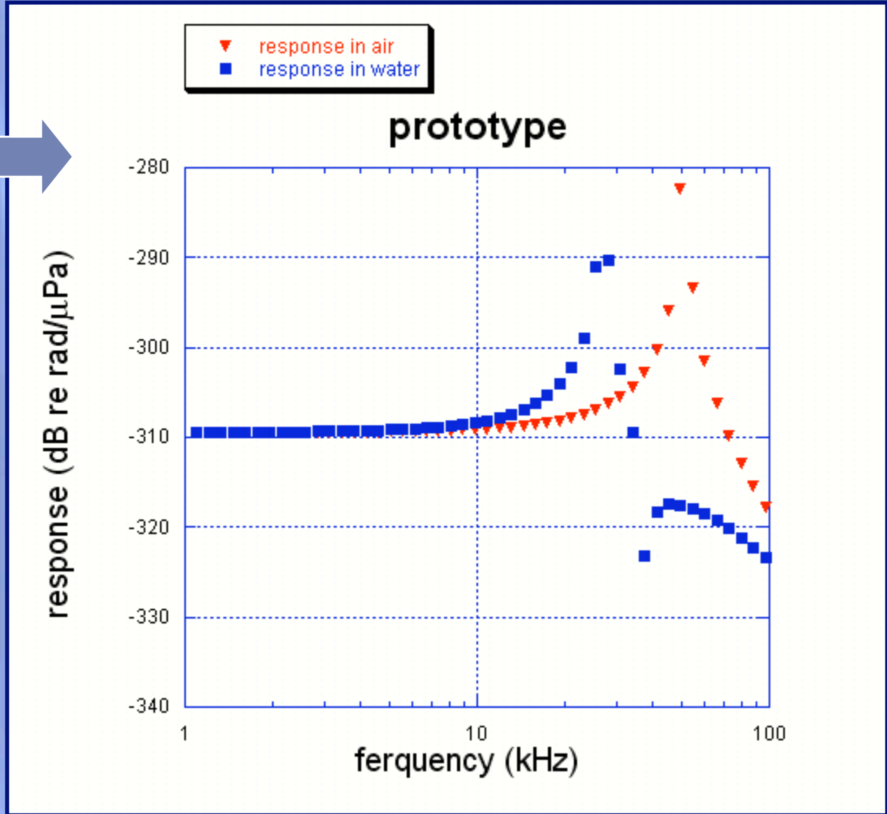


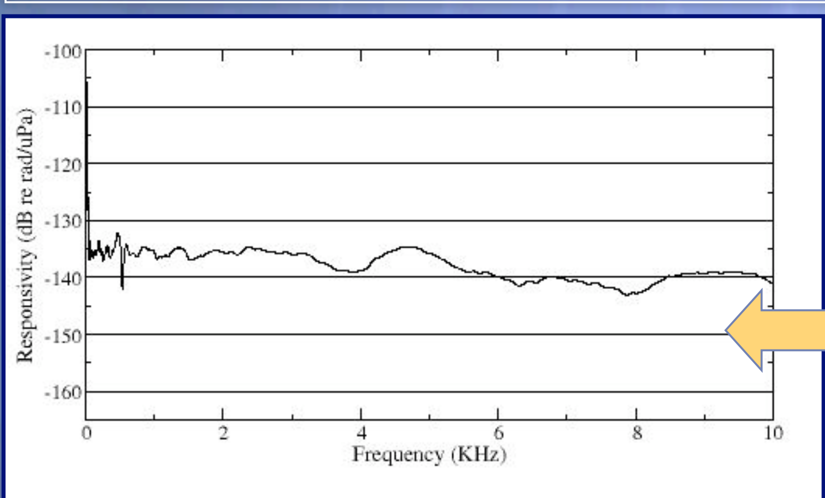


- Advantages include:
- *(Relative) ease of fabrication*
- Immune from EMI
- *No need for ADC*
- Could be arranged in large arrays using multiplexing

Sensor Development

- Prototypes developed and characterised
  Main challenges:
  - *to improve response in 20kHz-30kHz region*
  - Improve operating depth

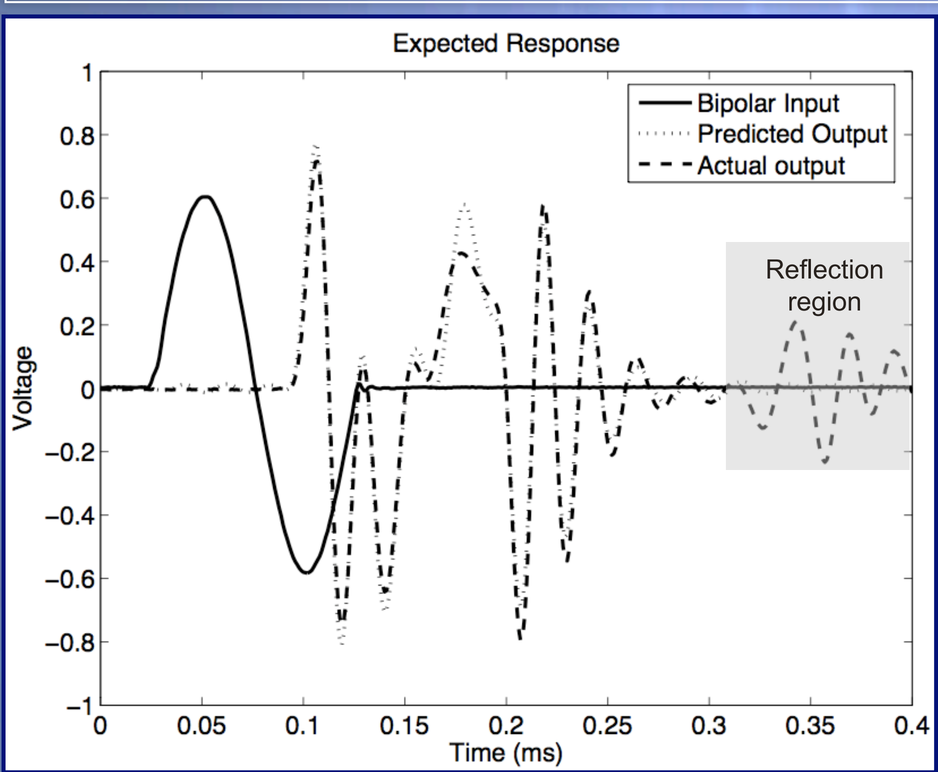


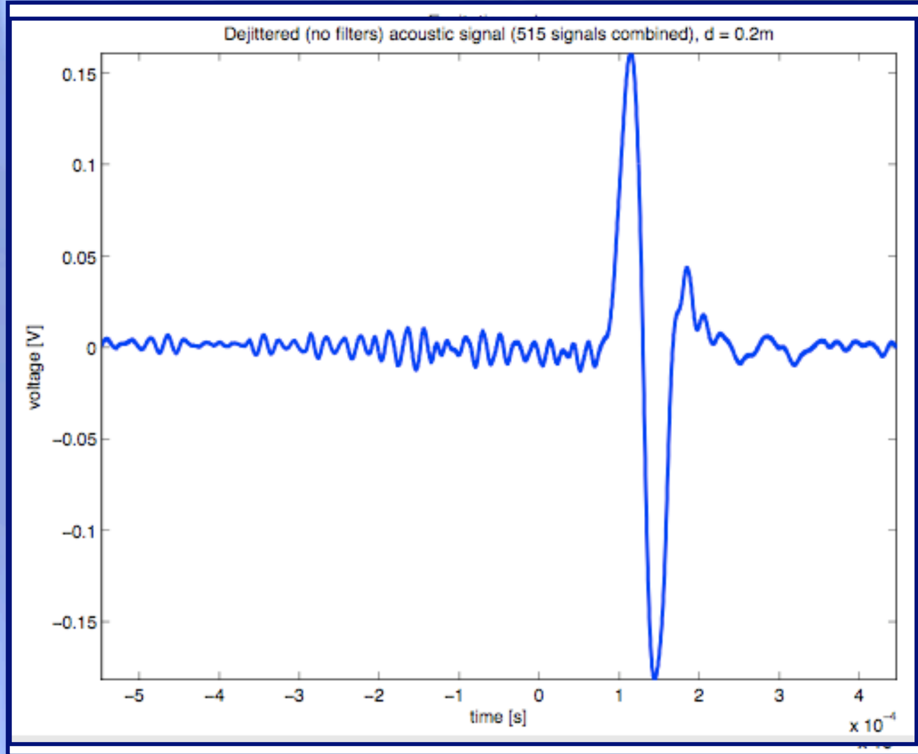


- Minimum detectable signal at 5kHz is 450μPa
- *Promising technique*

Acoustic Calibration

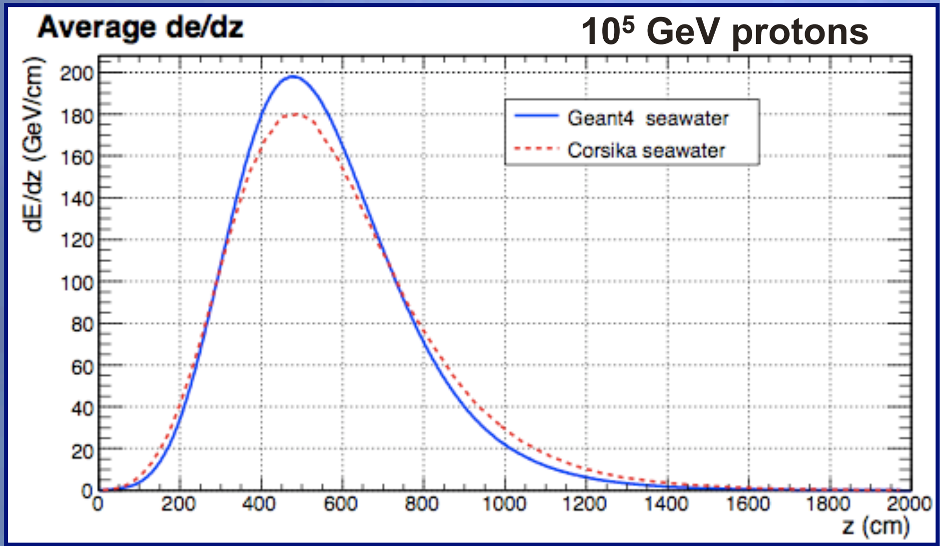
- Work done by the ACORNE collaboration
- Using signal processing techniques (including equivalent circuits - able to very accurately characterise a hydrophone in both phase and amplitude

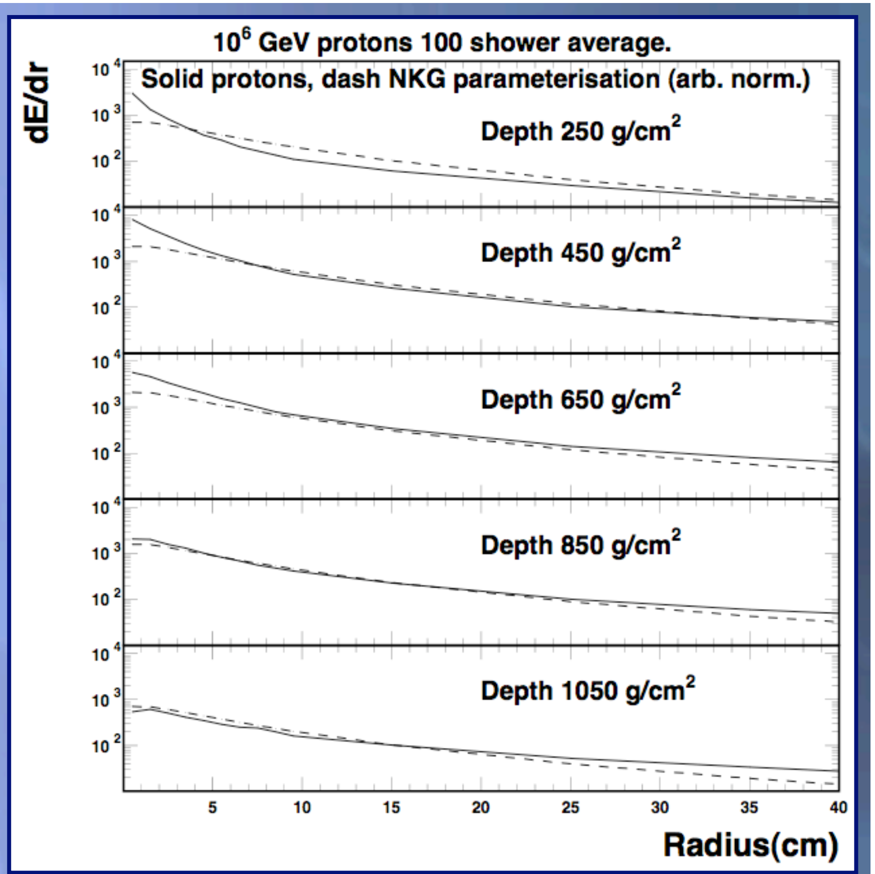


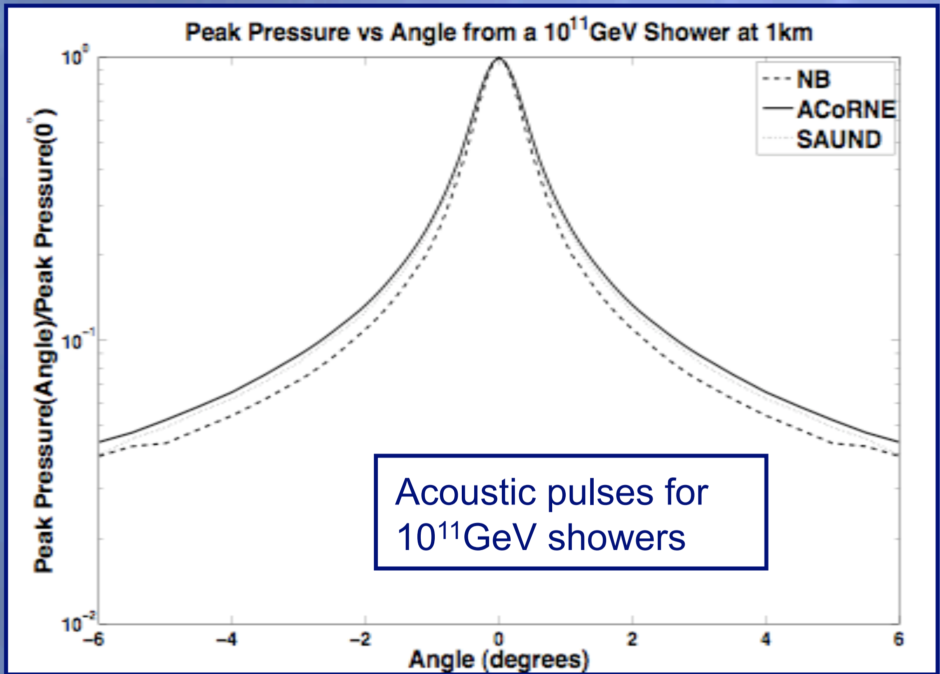


- ACORNE group are now using this technique to transmit accurate bipolar pulses
- Will be done above the Rona array in early August

Simulation Work

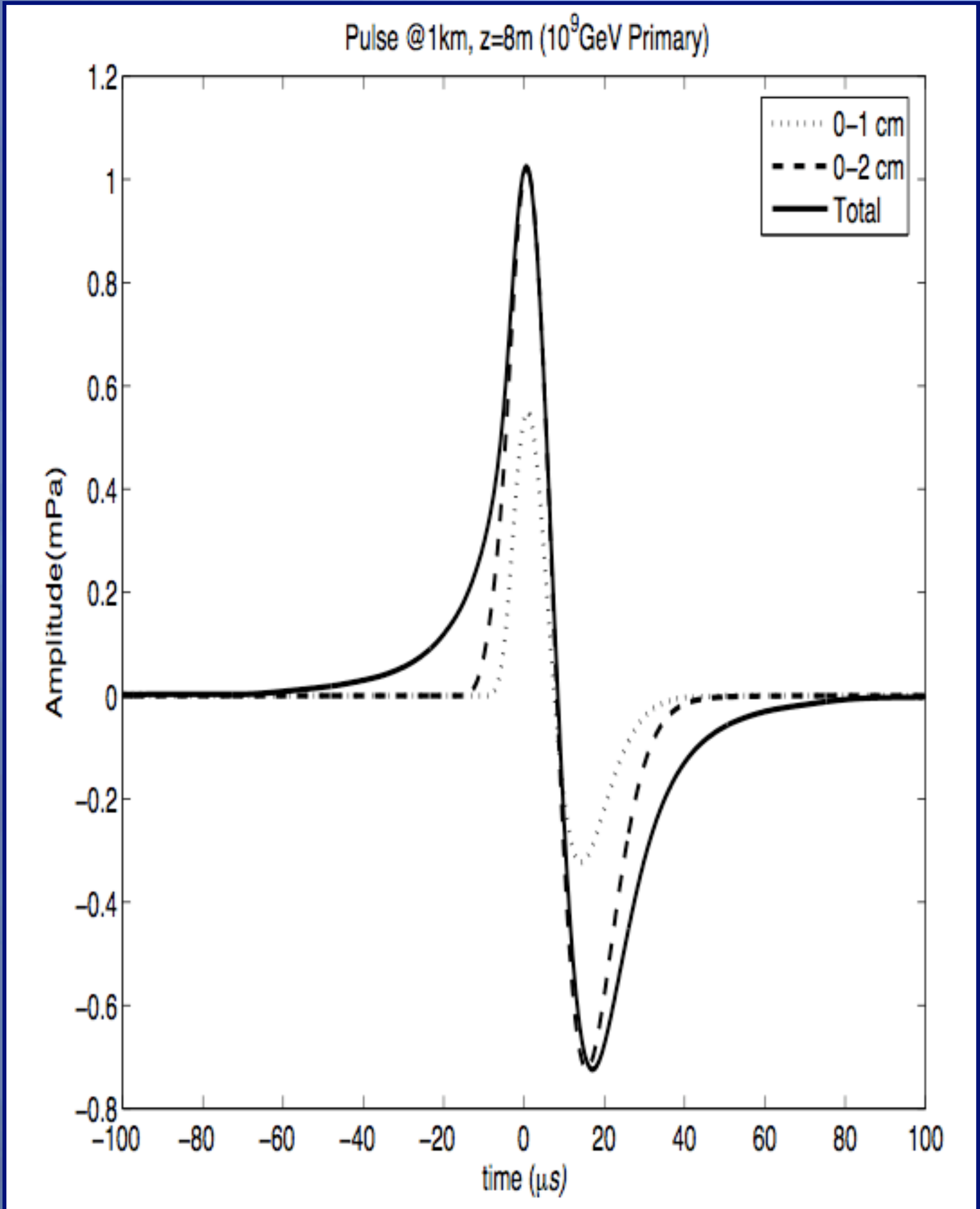






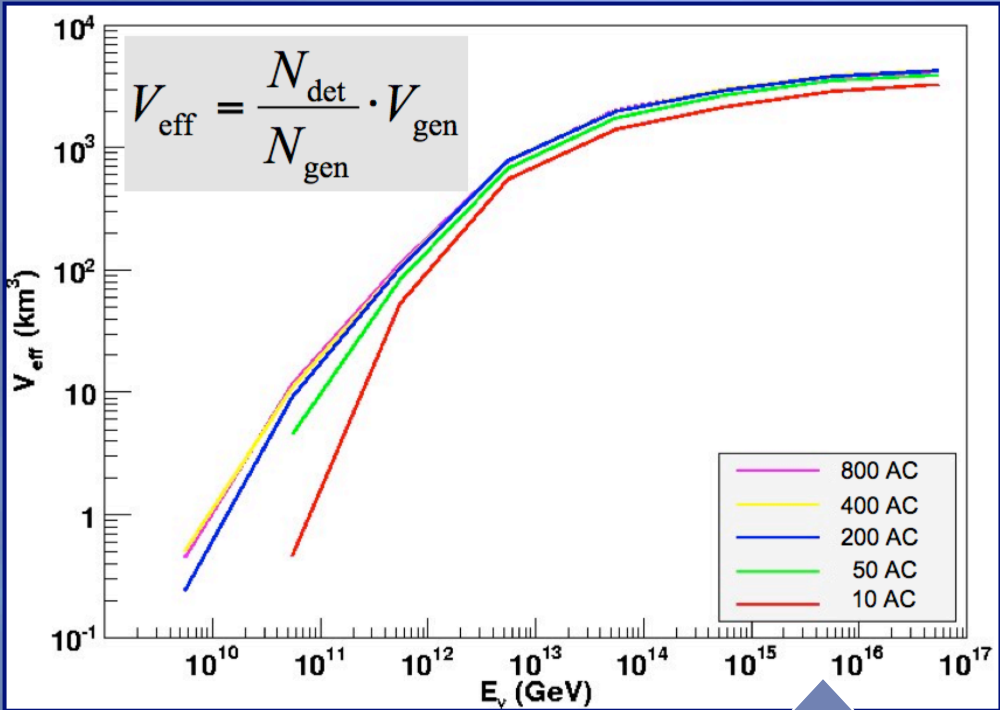
- The acoustic signal is very sensitive to the core of the hadronic cascade
- *CORSIKA has been modified to make it work in water*
- Cross-checks with GEANT4
- *Avoids extrapolating low energy Toolkits such as GEANT4*

Simulation Work

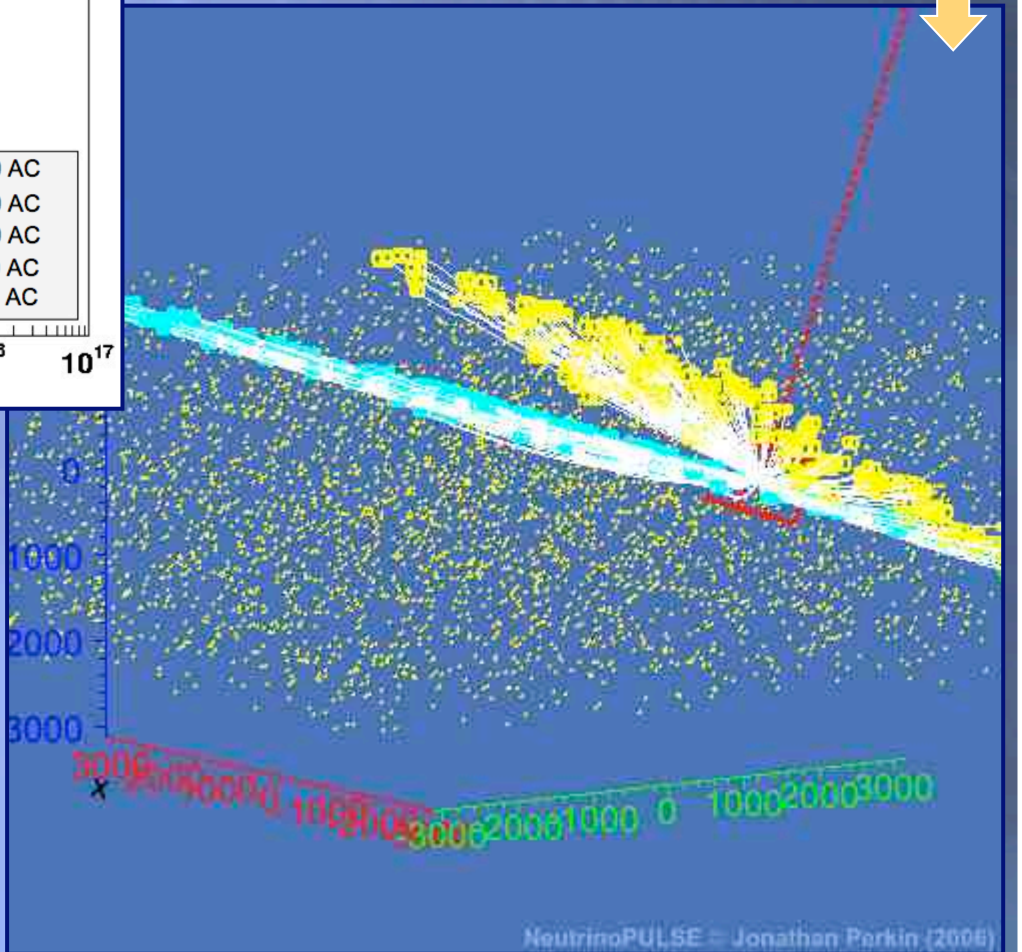


- Generated acoustic pulses using CORSIKA parameterisations
- The acoustic signal 1km from shower axis in the pancake plane
- Average of 100 CORSIKA showers at 10^9 GeV in water
- See arXiv:0704.0125 [astro-ph] for further information

Sensitivity Calculations



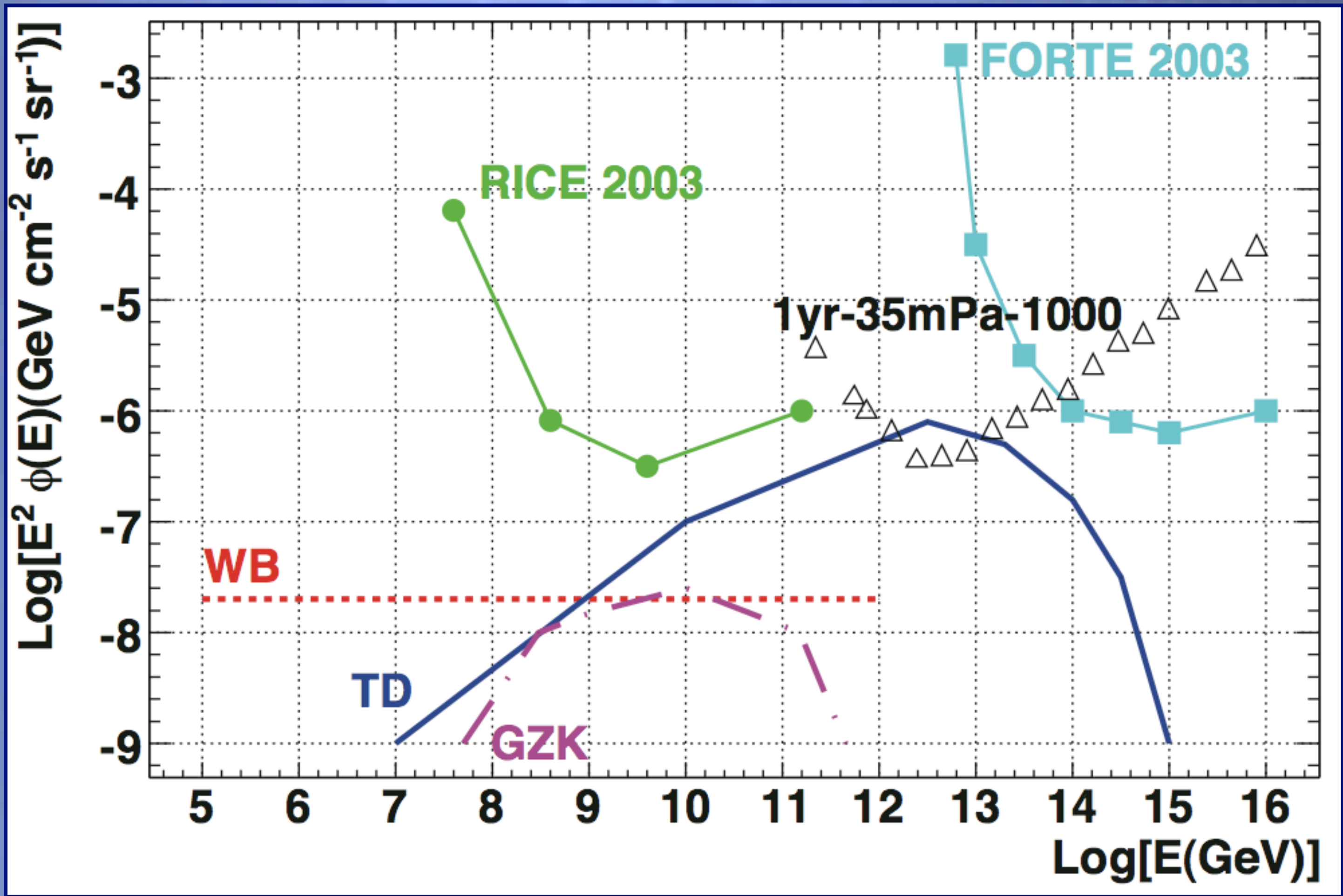
- Current studies are concentrating on the effects of refraction
- *Linear Sound Velocity Profile (SVP) distorts the acoustic pancake into a hyperbola*



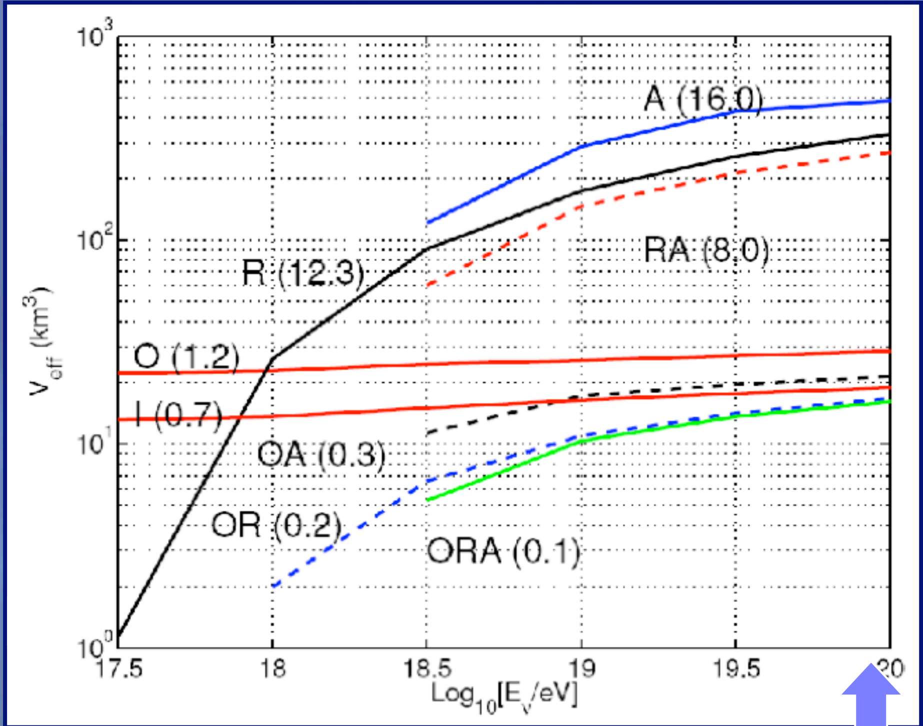
- Effective volume for a 1 km^3 array instrumented with different numbers of ANTARES-style *acoustic storeys*
- *No improvement in effective volume above 200AC/km^3*
- Detection threshold 5mPa

Sensitivity Calculations

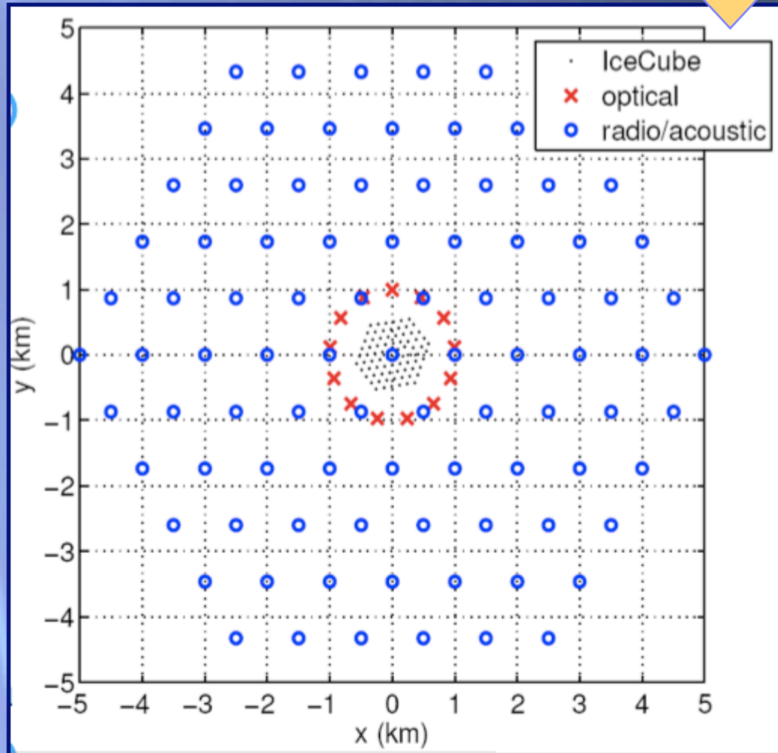
- Example curve for 1 year, 1000 hydros in a volume of 1 km^3 with 35mPa hydrophone threshold



Sensitivity Calculations



- Considering Hybrid arrays incorporating optical, radio and acoustic technologies
- *Cross-calibration between technologies should be possible*
- Yields up to 20 events per year



- Effective volume for hybrid arrays involving extending beyond IceCube with strings of radio and acoustic sensors
- *IceCube plus 5x2 radio and 300 acoustic sensors per string*
- See D. Besson, astro-ph/0512604

Summary

- *The acoustic detection of UHE neutrinos is a promising technique that would complement high energy neutrino detection using the optical and radio techniques*
- It is likely that any development of a large volume acoustic sensor array would be in parallel with the infrastructure of first and second generation optical Cerenkov neutrino telescopes
- *This is already starting to happen (ANTARES-AMADEUS, IceCube-SPATS-AURA)*
- Multi-messenger observations of astrophysical objects clearly provide valuable information, this is also true at ultra high energies

ARENA Workshops

- Acoustic and Radio detection EeV Neutrino Activities
- DESY (2005) and Newcastle (2006)
- *Follow on from RADHEP (2000), Stanford workshop (2003)*
- ARENA 2008 will be in Rome!